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Residual Strength and Life Prediction of Composite Laminates

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K. L. Reifsnider and Suresh Subramanian

**Virginia Polytechnic Institute and State University
Dept. of Engineering Science and Mechanics
Blacksburg, VA 24061-0219**

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RESIDUAL STRENGTH AND LIFE PREDICTION OF COMPOSITE LAMINATES

A systematic study was conducted to examine the influence of fiber surface treatment and sizing on the formation of fiber-matrix interphase and its effects on the mechanical properties of composite laminates. Three material systems having the same Apollo graphite fibers and HC 9106-3 toughened epoxy matrix, but with different fiber surface treatments and sizings were used in this study. They are designated as 810 A, 820 A and 810 O composite systems. The fibers used in the 810 A and 820 A systems received 100 % and 200 % industry standard surface treatments respectively, and were sized with Bisphenol-A unreacted epoxy material. The 810 O system was manufactured with 100 % surface treated fiber that were sized with pvp (polyvinylpyrrolidone), a thermoplastic material.

Presence of different interphase in these materials was confirmed using a permanganic etching technique. Results indicate that the region near the fiber surface constituting the interphase is essentially made of linear chain polymeric material and is discontinuous in the 810 A system. The morphology of the interphase in the 810 O system is significantly different from that in the 810 A system. In addition to the region near the fiber surface that contains linear chain polymeric material, the interphase appears to have a gradient morphology. The cure chemistry of the matrix material near the fiber is affected by the presence of pvp. The distribution of pvp is also observed to be highly non-uniform in the 810 O system. In contrast, the 820 A system did not possess a well defined interphase.

Mechanical tests on unidirectional composites reveal significant differences in these material systems. The 810 O system has a 10 % greater longitudinal tensile strength and 25 % greater failure strain compared to the 810 A system. The longitudinal tensile stiffness of the 810 O system however is 16 % lower than that of the 810 A system. The 810 A and 820 A systems have similar longitudinal tensile properties. Transverse tensile test results indicate that the 820 A system has the highest tensile strength while the 810 O system has the lowest strength.

The (0,90₃)_s cross-ply laminates from the three material systems exhibit different damage mechanisms and failure modes under monotonic tensile loading. Transverse matrix cracking occurs at significantly lower load levels in the 810 O laminates compared to the 810 A laminates. Also, the 810 O laminates reveal extensive longitudinal splitting, local delaminations and greater number fiber fracture prior to final failure. The 820 A laminates exhibit less damage (transverse cracks, delamination and fiber fractures) compared to the 810 A laminates.

Fatigue tests at $R = 0.1$ and 10 Hz frequency were conducted at various load levels to characterize the long-term behavior of (0,90₃)_s cross-ply laminates. Stiffness reduction, penetrant enhanced x-ray radiography and scanning electron microscopy techniques were used to monitor damage progression. Results shown in figure 1 indicate that the nature of

the interphase region has significant effect on the long-term behavior of cross-ply laminates. The pvp sized 810 O laminates have longer fatigue lives at higher load levels and shorter fatigue lives at lower load levels compared to the epoxy sized 810 A laminates. The 820 A laminates have longer life compared to the other two materials systems, at all three load levels. The damage mechanisms and failure modes in cross-ply laminates under long-term loading are significantly influenced by the nature of the fiber-matrix interphase. Figure 2 shows that the 810 O material exhibits greater stiffness reduction than the other two materials. X-ray radiographs of interrupted fatigue tests shown in figure 3 indicate that there is greater damage in the form of matrix cracking, interfacial debonding and local delaminations in the 810 O laminates compared to the other two materials. In addition, the failed specimen indicate that the epoxy sized 810 A and 820 A systems exhibit a brittle stress concentration controlled failure, while the pvp sized 810 O system exhibits a global strain controlled failure.

A micromechanics model was developed to investigate the role of fiber-matrix interphase on the tensile strength of unidirectional laminates. A new parameter called the 'efficiency of the interface', is introduced in the model. A simple scheme that uses the experimentally determined tensile modulus of unidirectional laminates in a concentric cylinders model, is described to estimate the interfacial efficiency. Interfacial debonding is included in the model by considering the matrix to behave in an elastic-perfectly plastic manner. The predictions from the model indicate that the fiber-matrix interphase can be completely characterized using two parameters : Interfacial efficiency and interfacial shear strength. The model also indicates that the tensile strength of a unidirectional laminate can be optimized by tailoring the interphase (figure 4). The predicted unidirectional tensile strength and failure modes match well with the experimental data. The influence of the interphase on the tensile fatigue performance of cross-ply laminates is predicted using this micromechanics model in a cumulative damage scheme. The degradation of the interphase is modeled using the interfacial efficiency parameter. The predicted fatigue lives and failure modes agree well with the experimental results.

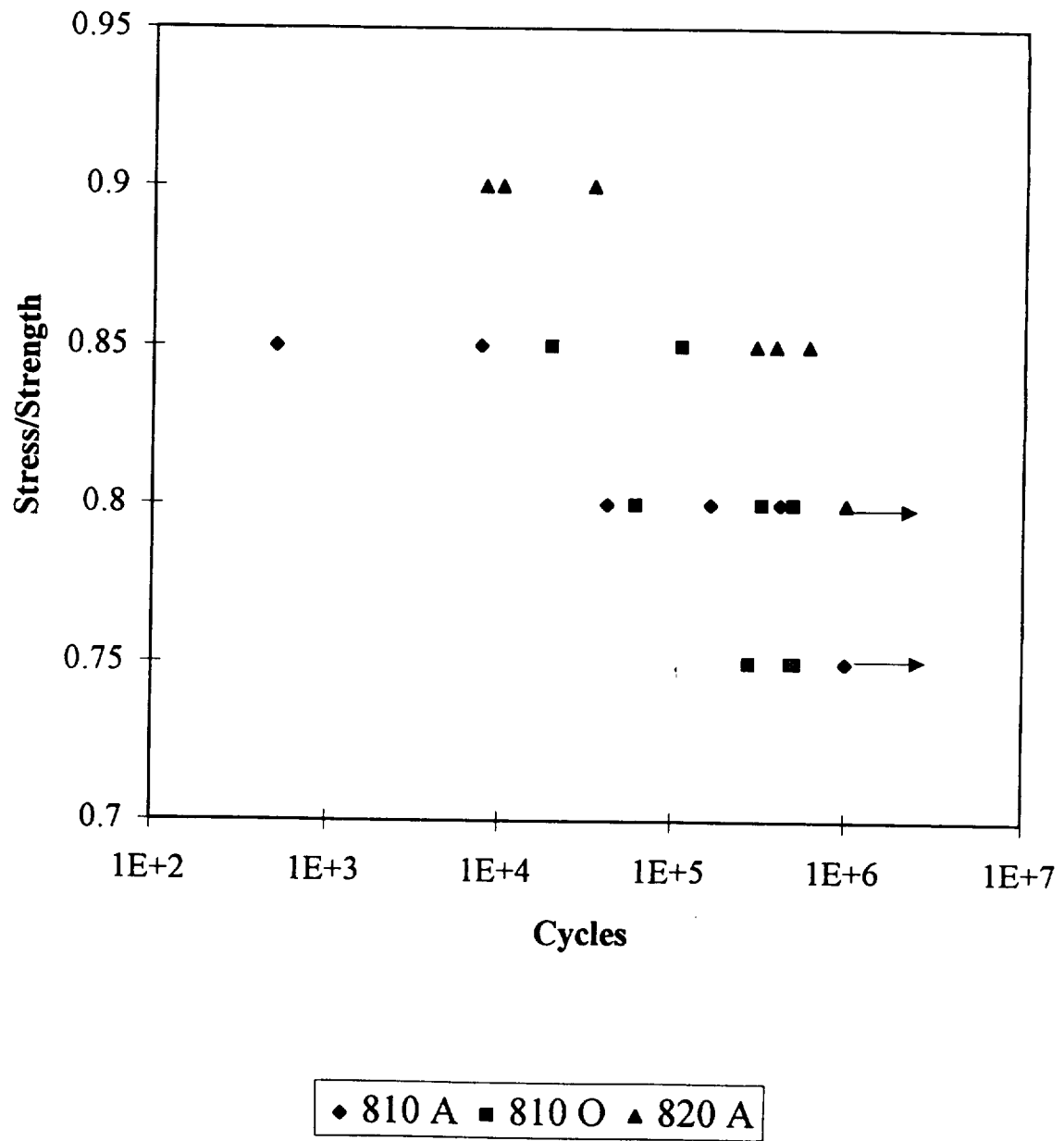


Figure 1 Fatigue S-N curves for 810 A, 810 O and 820 A cross-ply laminates.

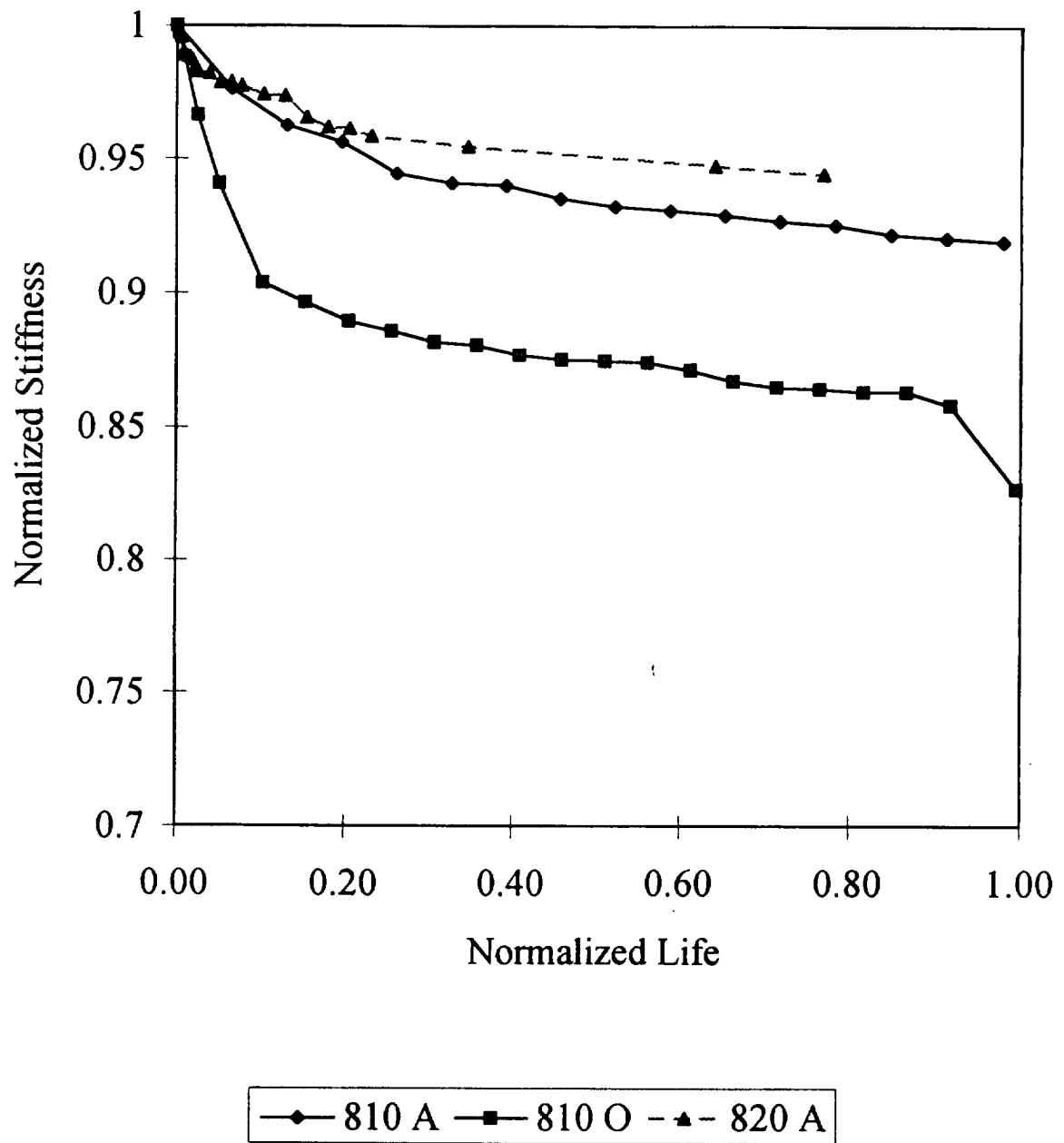


Figure 2 Stiffness reduction in 810 A, 810 O and 820 A laminates under fatigue loading at (80% load level).

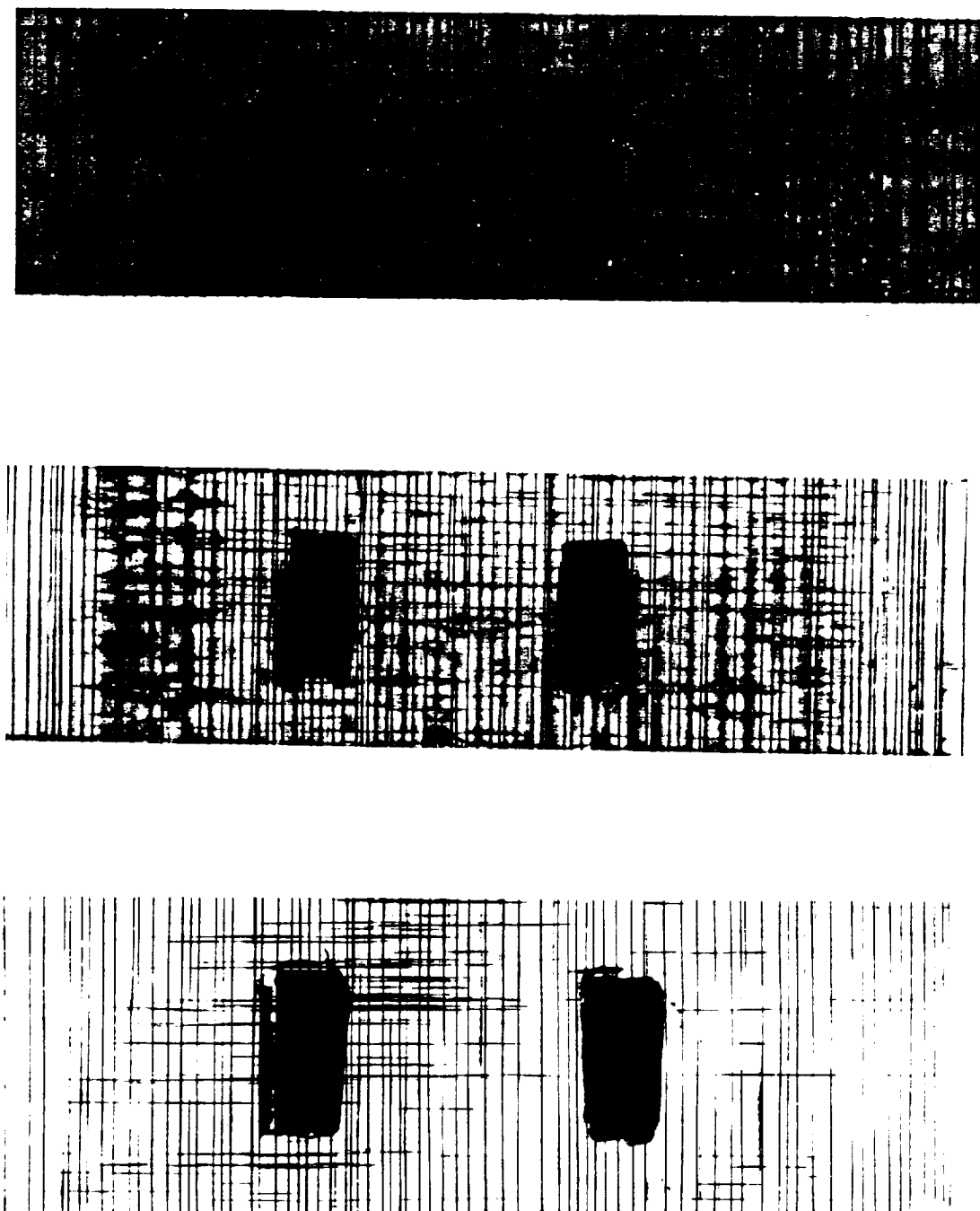


Figure 3 X-ray radiograph of cross-ply laminates
 Top : 810 A laminate after 1 million cycles at 75 % load
 Middle : 810 O laminate after 200,000 cycles at 75 % load
 Bottom : 820 A laminate after 1 million cycles at 80 % load

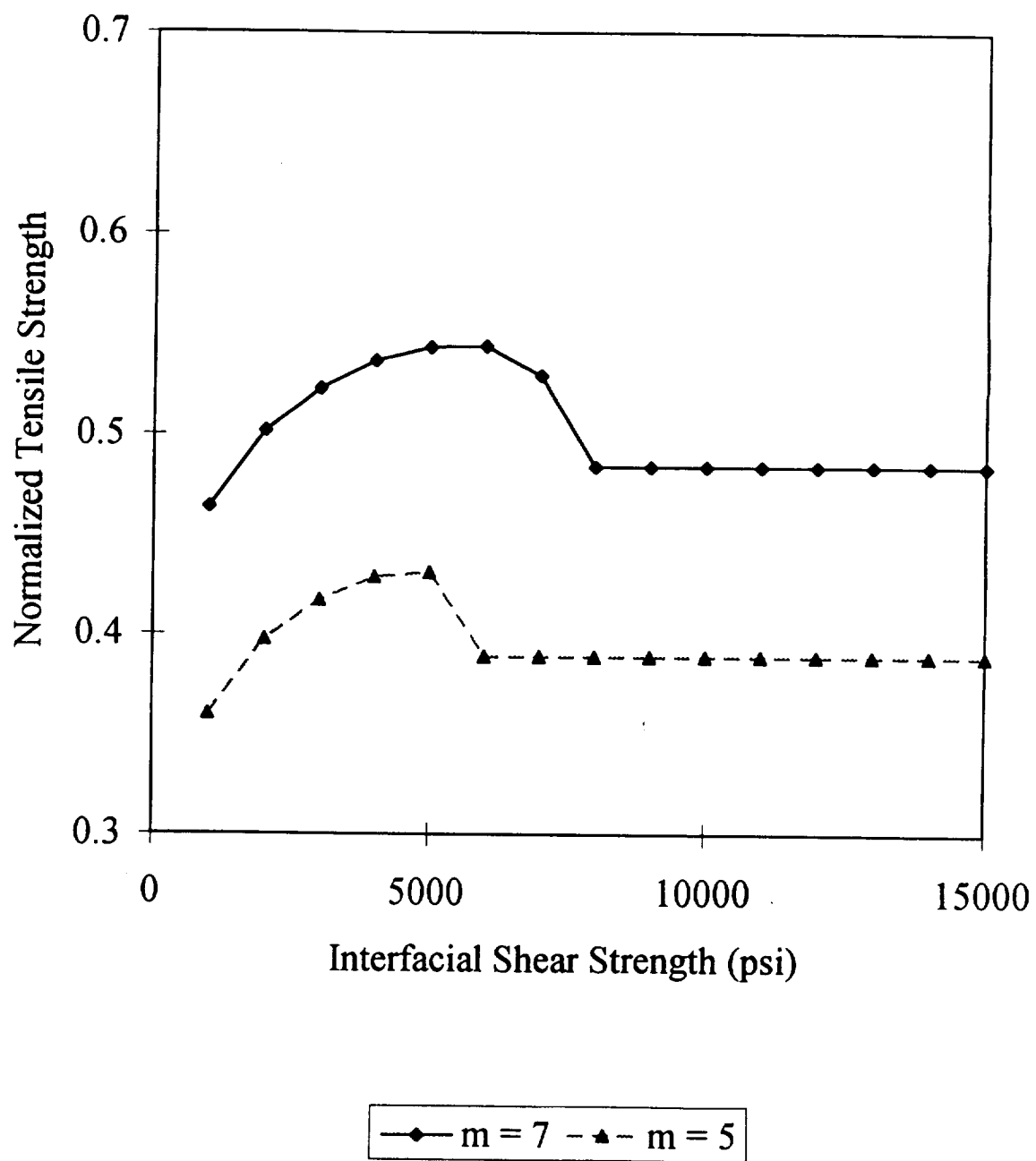


Figure 4 Predicted variation of tensile strength of unidirectional laminates with interfacial shear strength.